

Faint galaxies and the X-ray background

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We summarise our recent work on the faint galaxy contribution to the cosmic X-ray background (XRB). At bright X-ray fluxes (in the ROSAT pass band), broad line QSOs dominate the X-ray source population, but at fainter fluxes there is evidence for a significant contribution from emission-line galaxies. Here we present statistical evidence that these galaxies can account for a large fraction of the XRB. We also demonstrate that these galaxies have significantly harder X-ray spectra than QSOs in the ROSAT band. Finally we present preliminary findings from infra-red spectroscopy on the nature of this X-ray emitting galaxy population. We conclude that a hybrid explanation consisting of obscured/Type 2 AGN surrounded by starburst activity can explain the properties of these galaxies and perhaps the origin of the entire XRB.

Key words: Active galactic nuclei, X-ray background, deep surveys

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1. Introduction

Deep ROSAT surveys have revealed that broad-line QSOs account for at least 30% of the total 0.5 – 2 keV XRB. Analyses of the number count distribution and luminosity function of QSOs, however, suggests that they are unlikely to form more than $\sim 50\%$ of the XRB at these energies (Boyle et al 1994, Georgantopoulos et al 1996), although we note that recent work by Schmidt et al (1997) and Hasinger et al (1997) disputes this claim. Furthermore, it has been known for many years that the X-ray spectra of QSOs are much steeper than the spectrum of the XRB, leading to the so-called ‘spectral paradox’ (Gendreau et al 1995). A faint source population with a flatter X-ray spectrum is required to account for the remainder of this background radiation.

In recent years it has become clear that a population of X-ray luminous narrow emission-line galaxies (NELGs) could provide a possible explanation, perhaps dominating the X-ray source counts at faint fluxes (Boyle et al 1995, McHardy et al. 1997, Carballo et al 1995, Griffiths et al 1996). We refer to these X-ray loud objects as ‘narrow-line X-ray galaxies’ (NLXGs) to distinguish them from the field galaxy population. The nature of the X-ray emitting mechanism in these galaxies will be discussed further in Section 4, but we will conclude that many of these

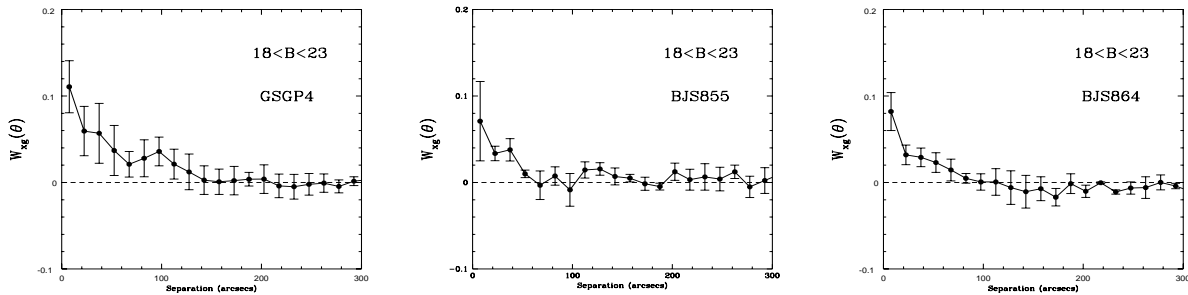


Figure 1: The cross-correlation function $W_{xg}(\theta)$ of the unresolved $0.5 - 2\text{keV}$ X-ray background with faint $18 \leq B \leq 23$ galaxies on 3 deep fields (see Almaini et al 1997b).

objects contain low luminosity or obscured AGN (see eg. Comastri et al 1995). In this sense the entire XRB could still be due to ‘AGN’ rather than two distinct classes of X-ray source. The most significant problem in assigning faint galaxies to X-ray sources comes from the confusion associated with the relatively large X-ray error box (see Hasinger et al 1997). To overcome this confusion, one must adopt a statistical approach.

2. Probing the galaxy contribution by cross-correlation techniques

The clearest evidence that faint galaxies could be important contributors to the XRB came from the study of Roche et al (1995), who cross-correlated faint ($B < 23$) galaxy catalogues with deep X-ray observations, thus avoiding the problems associated with source confusion. In Almaini et al (1997b) we performed an independent test of the Roche et al results on new deep ($\sim 50\text{ks}$) *ROSAT* exposures and for the first time attempted to measure the evolution in the X-ray emissivity of faint galaxies with redshift. The cross-correlation of unidentified X-ray sources with faint galaxies indicated that these could account for $20 \pm 7\%$ of all X-ray sources to a limiting flux of $\sim 4 \times 10^{-15} \text{erg s}^{-1} \text{cm}^{-2}$ in the $0.5 - 2.0 \text{keV}$ band. To probe deeper, cross-correlations were also performed with the residual, unresolved XRB images. Significant signals were again obtained on all 3 *ROSAT* fields (see Figure 1), independently confirming the results obtained by Roche et al (1995).

To constrain the evolution of X-ray emissivity with redshift, we used the magnitudes of the thousands of catalogue galaxies as probes of their redshift distribution, adapting the formalism of Treyer & Lahav (1996). We found evidence for very strong evolution in the mean X-ray luminosity of the form $\langle L_x \rangle \propto (1+z)^{3.22 \pm 0.98}$. This represents the first evidence that the X-ray emission from faint galaxies evolves as strongly as AGN. Similar results were obtained by analysing small numbers of bright narrow emission-line galaxies emerging from deep *ROSAT* exposures (Griffiths et al 1996, Boyle et al 1995). A simple extrapolation to $z=2$ suggests that faint galaxies can account for $\sim 40 \pm 10\%$ of the total XRB at 1keV .

3. The X-ray spectra of faint ROSAT sources

In Almaini et al (1996) we presented an analysis of the X-ray spectra of all X-ray sources from our deep survey. The results confirmed the trend found by Hasinger et al (1993) and Vikhlinin et al (1995) that the average source spectra harden towards fainter fluxes. Hardness ratios for the stacked spectra of all sources as a function of flux are shown on Figure 2(a).

Using the optical identifications available for most of these sources, it was found that ordinary, broad-line QSOs are not responsible for this spectral hardening (Figure 2b). This implied that the change in mean spectra was due to the emergence of another source population. Our cross-correlation results suggest that $20 \pm 7\%$ of the remaining, unidentified sources are due to faint galaxies, but confusion problems prevent us from determining exactly which X-ray sources are responsible. We therefore selected a restricted sample of the most likely galaxy candidates with brighter optical magnitudes ($B < 21.5$) and lying within 20 arcsec of the X-ray source. The hardness ratios for the 15 emission-line galaxies satisfying this criteria are shown in Figure 2b. We expect approximately 3 of these galaxies to be spurious identifications, but nevertheless it is clear that their mean X-ray spectra are significantly harder than those of QSOs (Almaini et al 1996, Romero-Colmenero et al 1996). Hence the X-ray spectra provide

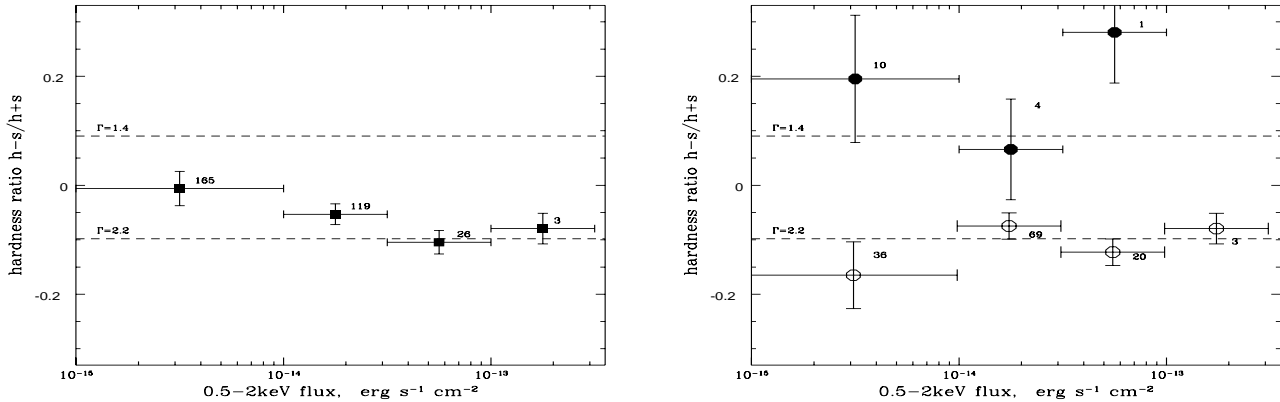


Figure 2: (a) 0.5-2 keV hardness ratios as a function of flux for the stacked spectra of all X-ray sources from 5 deep ROSAT fields. In (b) we separate the QSOs (unfilled circles) from the subset of 15 narrow emission line galaxies considered to be the most unambiguous identifications (filled circles). The number of X-ray sources within each bin is indicated. For comparison, the hardness ratios for two power-law models are also shown.

further evidence that NLXGs may finally provide the solution to the origin of the XRB. The key test is to examine their mean spectral properties with a large sample at higher energies, which will be possible with AXAF or XMM.

4. Understanding the nature of NLXGs

There is mounting evidence that a population of X-ray luminous ‘galaxies’ could finally provide a solution to the origin of the XRB. The important question now is to understand the nature of this unusual activity. Using standard optical emission line ratios, these objects appear on the borderline between starburst and Seyfert 2 classification and in most cases the distinction is very ambiguous (Boyle et al 1995, McHardy et al 1997). One possibility is that these are a new type of evolved starburst galaxy in which the X-ray emission comes from massive X-ray binaries (Griffiths and Padovani 1990). No local starburst galaxies have been found with such hard X-ray spectra however. These galaxies are also significantly more X-ray luminous than any known starburst galaxies, and their far infra-red fluxes are generally too low for the X-ray emission to be entirely due to starforming activity (Iwasawa et al 1997). The most likely explanation is that the hard X-rays come from an obscured active nucleus. Such models can readily reproduce the spectrum of the X-ray background (Comastri et al 1995). Recent work by Hasinger et al (1997; see also these proceedings) has suggested that many of these galaxies would indeed be classified as AGN in higher signal to noise optical spectra, albeit as low luminosity and/or type 2 AGN.

If these objects are obscured AGN, one might expect to detect broad emission lines in the infra-red waveband (the dust extinction at K is approximately 6 magnitudes lower than in the V band). We have recently obtained UK Infra-Red Telescope CGS4 spectroscopy for a small number of NLXGs. Of the 5 objects studied so far, none show any evidence for the expected broad Paschen emission lines. In most cases, this implies an absorbing column of at least 5×10^{22} atom cm^{-2} (if an AGN is present). Such columns are inconsistent with the large ROSAT luminosities below 1 keV, unless there is some contribution from an additional source of soft X-ray flux. In at least one object, the detection of highly ionized Si[VI] clearly indicates the presence of an AGN, despite the non-detection of broad Paschen lines (Figure 3). As such, this is similar to the optical narrow-line objects detected by Hasinger et al (1997). A plausible way to account for these properties is to postulate a hybrid model, consisting of an obscured AGN surrounded by starforming activity. Such a model would certainly explain the ambiguous optical line ratios seen in these objects. The hard ASCA NLXG detected by Iwasawa et al (1997) shows clear evidence for this dual behaviour. As discussed in Fabian et al (1997), obscuration by nuclear starburst activity may be an inevitable consequence of triggering a low luminosity AGN, and could perhaps account for the obscuration of the entire hard XRB.

5. Conclusions

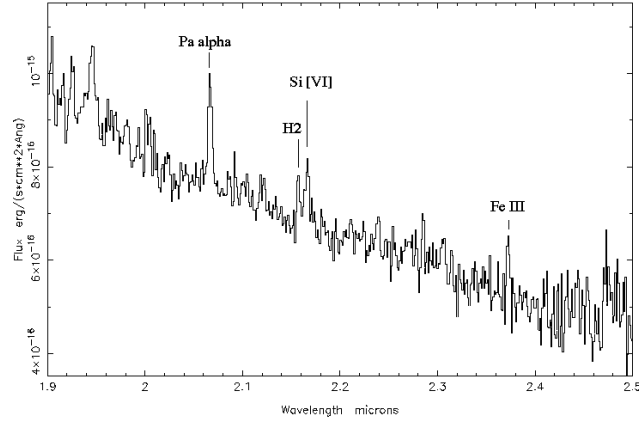


Figure 3: Infra-red spectrum of a NLXG at redshift $z = 0.105$. The coronal Si[VI] line proves the existence of an AGN, although the non-detection of broad Pa α implies an obscuring column $n_H > 5 \times 10^{22} \text{ atom cm}^{-2}$.

There is now overwhelming evidence for the existence of a population of X-ray luminous galaxies, which could explain the remainder of the XRB. Our cross-correlation analysis suggests that these objects could account for $40 \pm 10\%$ of the XRB at 1keV. In addition, the individually identified galaxies show significantly harder X-ray spectra than QSOs, more consistent with that of the XRB. Obscured and/or low luminosity AGN provide the most natural explanation for this activity, although our infra-red spectroscopy and the optical properties of these galaxies suggest the presence of an additional soft X-ray component. A hybrid model consisting of an obscured AGN surrounded by starburst activity provides the most natural explanation for all observed properties.

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